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SULFUR CONTENT OF DOUGLAS-FIR FOLIAGE NEAR A PAPER MILL

Hilman C. Ratsch

National Ecological Research Laboratory
Corvallis, Oregon

August 1974

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by
Hilman C. Ratsch
Plant Ecology Branch
National Ecological Research Laboratory
Corvallis, Oregon 97330

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ABSTRACT

Douglas-fir needles were collected at eleven sites on the south side of the Columbia River in the vicinity of the Wauna Pulp and Paper Mill. The concentration of total sulfur in the needles ranged from 0.1 -- 0.2 percent at eight locations and 0.5 -- 1.0 percent at three hillside locations. Douglas-fir needles with high sulfur contents at the three hillside locations had no visible sulfur dioxide injury symptoms. The high sulfur values in needles indicate sulfur dioxide is being absorbed by the foliage and are on the borderline level of producing visible injury.

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INTRODUCTION

This study deals with Technical Assistance to the Northwest Region of the Department of Environmental Quality, State of Oregon. The Department has begun an evaluation of the feasibility of expanding the Crown Zellerbach pulp and paper mill at Wauna, OR. In the evaluation, SO_2 emissions were predicted to occur on a ridge and hillside downwind from the mill at concentrations sufficient to cause plant damage. The presence or absence of plant injury in this area may provide insight into the validity of the dispersion model estimates.

The Wauna pulp and paper mill is located on the south side of the Columbia River, approximately 25 miles east of Astoria at Wauna, Oregon. The hillside impact areas are on the north facing slope of the Columbia gorge approximately two to three miles southeast of the mill.

The objective of the study is to determine if SO_2 effluent has an effect on vegetation on the hillside impact areas. An SO_2 effect can be demonstrated by the observations of visible injury symptoms and/or the presence of high sulfur content in foliage.

METHODS AND MATERIALS

On March 8, 1974, eleven sites in the vicinity of the mill were visited to observe SO_2 injury and to collect samples of Douglas-fir foliage for sulfur analysis, see fig. 1 and Table 1. Most of the samples were collected either southwest or northeast of the mill. Three background samples were collected, one over the ridge from the Columbia gorge at Gnat Creek Forest Park and two on Fall Creek near Clatskanie.

The Douglas-fir needles collected were separated into current year and 1 year-old needle samples and submitted to Laboratory Services Branch (NERC) for total sulfur analysis.

Sulfur Analysis as a Diagnostic Technique

The visible effects of SO_2 on vegetation can be classified into two categories: acute and chronic injury. Acute injury is severe injury that is assoicated with high, short-term SO_2 concentrations, while chronic injury is light to severe injury associated with long term exposures and SO_2 concentrations sufficiently high to produce cell disruption. Much of the damage attributed to SO_2 may in fact be due to sulfuric acid and sulfates resulting from photochemical oxidation of SO_2.

In general, a large amount of sufate is found in leaves with chronic symptoms, whereas leaves that are acutely injured show only a small increase in sulfate content. However, large quantities of sulfate may accumulate in leaf tissue without visible leaf injury.

This can be explained by the mechanism in which plants are injured by SO_2. Acute injury does not occur if the rate of SO_2 absorption does not exceed the capacity of the plant to oxidize the sulfite to sulfate ions. Under long term SO_2 stress, sulfates thus formed may accumulate with the subsequent development of chronic injury symptoms. It is also feasible that sulfates may accumulate without reaching the critical level necessary to produce injury symptoms. Under natural conditions, sulfur analysis can reflect the magnitude of pollution to which vegetation has been exposed.

The exterior symptoms of acute or chronic injury caused by SO_2 emissions, in the form of necrosis chlorosis, and alterations in the physical appearance of the plants, are not sufficiently specific in themselves to allow the definite identification of SO_2 effects. However, injury resulting from chronic SO_2 exposure can usually be confirmed by the presence of a high sulfur content in leaves.

Normal Sulfur Content

Katz and McCallum[1] collected Douglas-fir foliage from many points in Washington and British Columbia and found the normal average sulfur content increased from .082 percent in current year needles to 0.149 percent in three-year-old needles. In another source[2] they state that the normal sulfur content of Douglas-fir leaves varied from 0.10 percent to a little over 0.20 percent.

They found that the sulfur content in some cases varied little from year to year while in others there was a definite increase in the older leaves. They assumed that where sufficient sulfur was available in the soil, the sulfur content of the needles increased with age, while at other low soil sulfur locations it remained constant.

Sulfur Accumulation

In 1930 and 1931, Douglas-fir needles were collected south of Trail, B.C., in the Columbia River Valley in the "Smoke Zone" of a large smelter and analyzed for sulfur. The sulfur content of the needles exposed to SO_2 was substantially higher than normal and decreased with increasing distance from the source. A three or four-fold increase over the average normal sulfur content occurred in some needles, although there were no symptoms of either acute or chronic injury.

In experimental plots Katz[2] found that sulfates accumulated in plant tissue were not toxic to leaves even in amounts three-five times greater than the original sulfur content.

Apparently, conifer needles can accumulate sulfur by absorption of sulfur dioxide at low concentrations over a long period without suffering visible injury. However, a heavy dose exposure over a short period may produce significant damage with only a slight increase in sulfur content.

If the normal sulfur content of Douglas-fir needles varies from 0.1 to 0.2 percent, the needles can conceivably accumulate sulfur in a range from 0.6-1.0 percent sulfur without resulting in any visible injury. This level of sulfur content indicates a high degree of pollution and is on the borderline of producing chronic injury symptoms.

RESULTS

On-Site Conditions

Severe injury symptoms on Douglas-fir were observed at the Bradley State Park location. Two trees on the slope below the parking lot had needle tip burn on the current year, one year and two year-old needles. The most severe tip burn occurred on the two year-old needles where 50-75 percent of the needle was brown and necrotic. Several branches on these two trees had considerable needle loss. Needle loss was most severe on the one and two year-old stems. The current needles had a chlorotic mottle type of injury.

On the basis of visible symptoms, the injury observed may be the result of SO_2 exposures, winter dessication or insect injury. Injury symptoms on Douglas-fir were also observed at locations No. 2 and 4, but were not specific as to cause.

Histological Examiniation

Needle tissue showing visible injury from Bradley State Park was examined histologically. Freehand cross sections were cut from needle tissue and mounted on slides in glycerin and water and examined under the microscope. The injury in Douglas-fir needles consisted of the collapse and pigmentation of the mesophyll in the upper part of the needle with occasional collapse and pigmentation of mesophyll below the vascular bundle, see Fig. 2. In most injured sections the guard cells of the stomata on the lower needle surface were pigmented and occasionally the epidermal and resin canal cells were also pigmented.

The microscopic injury symptoms observed on the Douglas-fir needle tissue point strongly to SO_2 and salt injury. In view of the somewhat elevated sulfur content of the needles, SO_2 is highly suspect as the cause of injury at Bradley State Park.

Sulfur Analysis

The results of the analysis for total sulfur on the collected Douglas-fir needles are shown in Table 2. The sulfur content of the background samples (0.10 - .21 percent sulfur) at locations No. 7, 10, 11 agrees with published sulfur values for "normal" Douglas-fir needles (0.1 - 0.2 percent sulfur). The hillside samples at locations 1, 2 and 3 from the suspected worst impacted area had sulfur contents of 0.49 - 1.05 percent. This indicates a high sulfur enrichment and in many cases was associated with visible injury symptoms.

At location No. 4 on the border of the worst impacted area and at locations No. 8 and 9 in the second impact area, the sulfur contents appear to be normal.

At Bradley State Park (locations No. 5 and 6) the sulfur contents are somewhat elevated and the current needles have as high or higher sulfur values than the one year-old needles.

CONCLUSION

Sulfur accumulation in Douglas-fir foliage is indicative of sulfur dioxide exposures and absorption. Whether leaf damage occurs depends not only on the amount of sulfur accumulated, but on the adsorption rate of sulfur dioxide as well as on the specific type and environment-conditioned plant resistance. At the hillside locations 1, 2 and 3 the sulfur content of foliage was several times normal, although there was no characteristic visible injury. At Bradley State Park (locations 5 and 6) the sulfur content of foliage was only slightly above normal, although sulfur dioxide injury symptoms were evident.

The sulfur content of Douglas-fir needles at locations 1, 2 and 3 indicate sulfur dioxide is being absorbed by foliage and is responsbile for the sulfur enrichment of the needles. The sulfur values are on the borderline level of producing visible injury.

The needle sulfur contents at locations 4, 8 and 9 are at a normal level and do not appear to be in the sulfur dioxide impact area. Based on visible injury symptoms and histological examination, the injury at Bradley State Park is probably due to sulfur dioxide.

Douglas-fir is intermediate in its sensitivity to sulfur dioxide (see Table 3) for concentrations that produce injury after short term exposures. Plants that fall in the sensitive category of susceptibility that may be observed in the future are as follows: alder, paper birch, Sitka mountain ash, Douglas maple, bitter cherry, chokecherry, blueberry elder, willow, aspen, alfalfa, sweet clover, larch and white pine.

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1. Katz, Morris and A. W. McCallum. "Effect of Sulphur Dioxide on Vegetation," Ottawa. National Research Council of Canada, 1939. Chapter IV, pp. 104-30.

2. Katz, Morris and A. W. McCallum. The Sulphur content of Douglas-fir and yellow pine in northern Stevens county, Washington, in 1935. Trail Smelter Question, Documents Series B, Appendix BB 5, 1936.

Table 1
Sample Locations in the Vicinity
of the Wauna Pulp Mill

Location	Description	Approximate Elevation	Age of Needle	Sample Number
1	on hillside between Westport and Taylorsville, solitary Doug-fir with broken top along logging road	300 ft.	current	11001
			1 year old	002
2	on hillside between Westport and Taylorville above location #1, small Doug-fir	500 ft.	current	003
			1 year old	004
3	on top of ridge (next to power line) between Westport and Taylorville. Large Doug-fir on outer perimeter of a group of trees	640 ft.	current	005
			1 year old	006
4	on low hillside just south of Taylorville, medium size Doug-fir in line of sight of plume	200 ft.	current	007
			1 year old	008
5	Bradley State Park on steep slope below parking lot	640 ft.	current	009
			1 year old	010
6	Bradley State Park on steep slope below parking lot	640 ft.	current	011
			1 year old	012
7	Gnat Creek Forest Park, large Doug-fir in heavy fir-hemlock stand upstream from park	240 ft.	current	013
			1 year old	014
8	Lost lake residential area south of Westport, solitary Doug-fir along road near dead end	400 ft.	current	015
			1 year old	016
9	EPA Westport Substation, large Doug-fir next to power line	240 ft.	current	017
			1 year old	018
10	Fall Creek Road, large Doug-fir adajacent to road	550 ft.	current	019
			1 year old	020
11	on logging road off Fall Creek Road small Douglas-fir in hemlock stand	700 ft.	current	021
			1 year old	022

Table 2
Total Sulfur Content of Douglas-fir
Needles in the Vicinity of the Wauna Pulp and Paper Mill

Location	Age of Needle	Sample Number	Percent Total Sulfur (dry weight)
1	current	11001	1.05
	1 year old	002	1.01
2	current	003	.98
	1 year old	004	1.01
3	current	005	.62
	1 year old	006	.49
4	current	007	.11
	1 year old	008	.21
5	current	009	.22
	1 year old	010	.17
6	current	011	.23
	1 year old	012	.24
7	current	013	.10
	1 year old	014	.15
8	current	015	.14
	1 year old	016	.14
9	current	017	.14
	1 year old	018	.15
10	current	019	.14
	1 year old	020	.15
11	current	021	.18
	1 year old	022	.21

Table 3
Sulfur Dioxide Concentrations that will Produce
Threshold Injury to Intermediate Susceptible Plants
For Short-Term Exposures.

Time Hours	$\mu g/m^3$	(ppm)
0.5	9170-31,440	(3.5-12)
1.0	6550-26,200	(2.5-10)
2.0	3930-19,650	(1.5-7.5)
4.0	1310-13,100	(0.5-5)
8.0	524-6,550	(0.2-2.5)

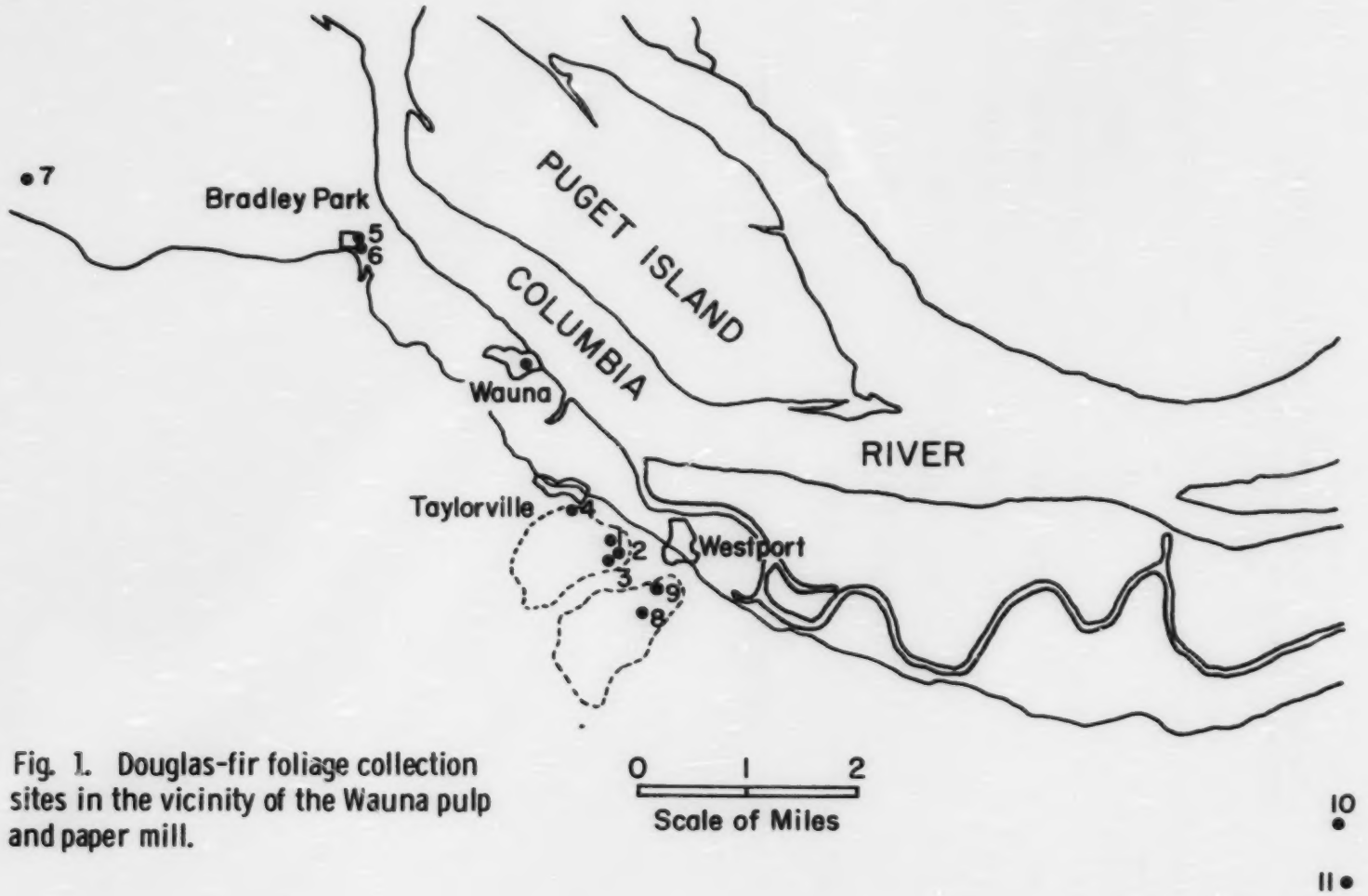

Fig. 1. Douglas-fir foliage collection sites in the vicinity of the Wauna pulp and paper mill.

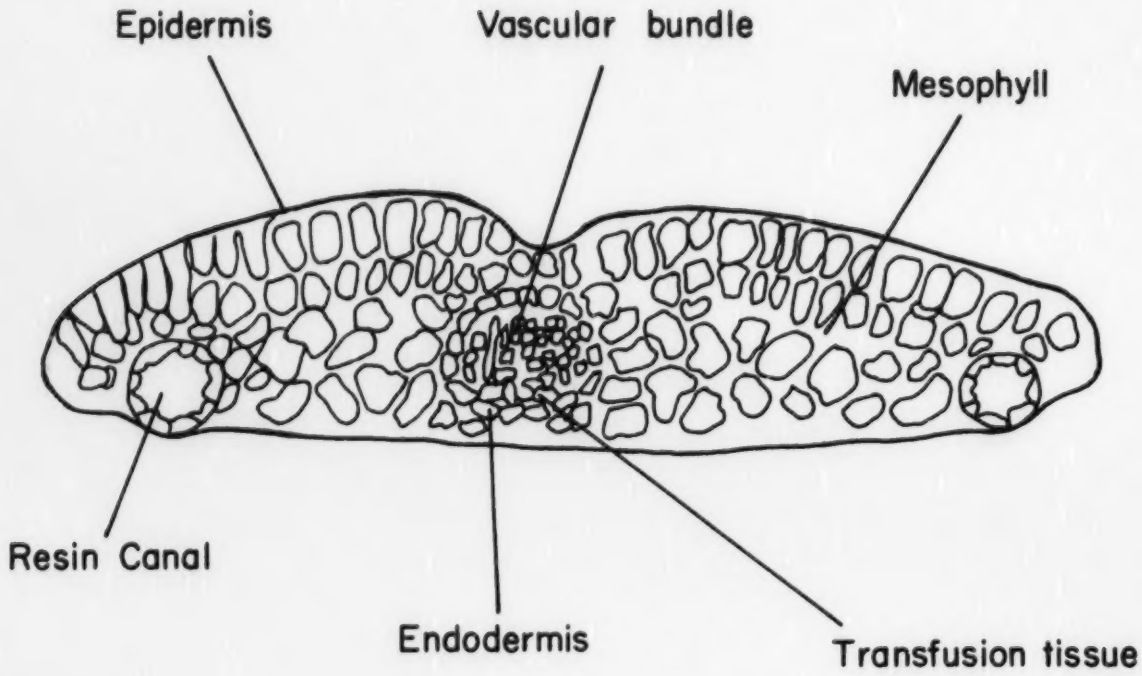

Fig. 2. Diagram illustrating, in cross section, the tissue showing collapse and pigmentation in a Douglas Fir needle.